

THE EFFECTS OF SALMON FISHERIES ON SOUTHERN RESIDENT KILLER WHALES

REFLECTIONS OF THE SCIENCE PANEL FROM WORKSHOP 1 AND GUIDANCE FOR WORKSHOP 2

Prepared for

National Marine Fisheries Service
(NOAA Fisheries)
7600 Sand Point Way NE,
Seattle, WA, USA
98115-0070

Fisheries and Oceans Canada (DFO)
200 – 401 Burrard Street
Vancouver, BC, Canada
V6C 3S4

Prepared by

Independent Science Panel of the
Bilateral Scientific Workshop Process to
Evaluate the Effects of Salmon Fisheries on
Southern Resident Killer Whales

with

David Marmorek and Alexander Hall
ESSA Technologies Ltd.
2695 Granville Street, Suite 600
Vancouver, BC V6H 3H4

November 15, 2011

Citation: **Hilborn, R., S. Cox, F. Gulland, D. Hankin, T. Hobbs, D.E. Schindler, A. Trites.** 2011. Reflections of the Science Panel from Workshop 1 and Guidance for Workshop 2. Prepared with the assistance of ESSA Technologies Ltd., Vancouver, B.C. for National Marine Fisheries Service (Seattle WA) and Fisheries and Oceans Canada (Vancouver BC). 41 pp.

Contents

1.0	Introduction.....	1
1.1	The Science Panel	1
1.2	Process to Date	2
1.3	Document Outline.....	3
2.0	Status of Killer Whales.....	5
2.1	Key Questions and Preliminary Responses	5
2.1	Information and Analyses Recommended prior to Workshop 2.....	6
3.0	Feeding Habits of Killer Whales	8
3.1	Key Questions and Preliminary Responses	8
3.2	Information and Analyses Recommended by Workshop 2.....	11
4.0	Fisheries that May Affect Prey Availability	12
4.1	Key Questions and Preliminary Responses	12
4.2	Information and Analyses Recommended by Workshop 2.....	14
5.0	Relationship between Chinook Abundance and Killer Whale Population Dynamics.....	19
5.1	Key Questions and Preliminary Responses	19
5.2	Information and Analyses Recommended by Workshop 2.....	23
6.0	Chinook Needs of Southern Resident Killer Whales	25
6.1	Key Questions and Preliminary Responses	25
6.2	Information and Analyses Recommended by Workshop 2.....	25
7.0	Chinook Abundance and Food Energy Available to Killer Whales.....	27
7.1	Key Questions and Preliminary Responses	27
7.2	Information and Analyses Recommended by Workshop 2.....	27
8.0	Reduction in Chinook Abundance and Food Energy from Fisheries.....	29
8.1	Key Questions and Preliminary Responses	29
8.2	Information and Analyses Recommended by Workshop 2.....	34
9.0	Ratio of Chinook Food Energy Available Compared to Chinook Food Energy Needed by Southern Residents with (and without) Fishing.....	36
9.1	Key Questions and Preliminary Responses	36
9.2	Information and Analyses Recommended by Workshop 2.....	37
10.0	Change in Killer Whale Population Growth Rates Annually, Abundance over Time and Species Survival and Recovery.....	39
10.1	Key Questions and Preliminary Responses	39
10.2	Information and Analyses Recommended by Workshop 2.....	40
11.0	References.....	41

1.0 INTRODUCTION

This document represents the responses of the Science Panel to the evidence presented leading up to, during, and subsequent to Workshop 1, with recommendations for additional information and analyses for Workshop 2. We have organized our responses, comments and recommendations around the topics and questions put forth by the NOAA/DFO steering committee. Our impressions and responses to questions in this document are preliminary. Further written information is expected prior to or at workshop 2 which could lead to substantial changes in our opinions prior to writing our final report.

In this document, we have avoided repeating background information that is readily available in other documents associated with this workshop process. Such relevant documents include:

1. **Process Description** – describes the overall workshop process, the role of the Science Panel, the Science Panel Chair, and the Science Facilitator, the flow of tasks through the entire process, and provides the contextual background to the key question.
2. **Reading List** – breaks the overall question into the topics used in this document, provides a contextual description of each topic, poses key questions for each topic, and provides an extensive list of relevant background literature.
3. **Workshop 1 Agenda** – lists all the speakers and presentations (and includes the Process Description).
4. **NOAA/DFO Questions & Answers** – provides answers to a list of short-term information requests that the Panel provided to the steering committee shortly after the workshop, prior to completing this document.
5. **Workshop 1 Proceedings** – includes questions and discussion from Workshop 1 integrated into a compilation of all of the responses (feedback, comments, recommendations, etc.) received from participants following the workshop.

1.1 The Science Panel

The Independent Science Panel comprises the following members:

Dr. Ray Hilborn (Chair),
School of Aquatic and Fishery Science, University of Washington, Seattle, WA

Dr. Sean Cox
School of Resource and Environmental Management, Simon Fraser University, Burnaby, BC

Dr. Frances Gulland
Marine Mammal Center, Sausalito, CA

Dr. David Hankin
Department of Fisheries Biology, Humboldt State University, Arcata, CA

Dr. Tom Hobbs

Natural Resource Ecology Lab, Colorado State University, Fort Collins, CO

Dr. Daniel Schindler

School of Aquatic and Fishery Science, University of Washington, Seattle, WA

Dr. Andrew Trites

Marine Mammal Research Unit, University of British Columbia, Vancouver, BC

1.2 Process to Date

The following provides a brief overview of the process followed by the Science Panel up to producing this document:

1. Initiation of the Science Panel

- Discussion of the task assigned to the Science Panel
- Lead and secondary reviewers assigned to each topic based on area of expertise

2. Literature Review

- Prior to Workshop 1, the Panel reviewed the NMFS 2010 Biological Opinion and the relevant background literature provided by the steering committee in the reading list and on both NMFS and ESSA websites for the workshop.

3. Workshop 1

- Listened to all of the presentations and asked questions of the presenters
- Engaged in the discussion periods; observed the issues raised by others
- Daily discussions within the Panel
- Focused discussion with individual presenters on details of the methods they used
- Afternoon Panel session on final day to review the evidence presented, discuss initial responses, clarify understandings of key issues, identify critical information gaps and priorities

4. Initial Responses

- Each of the Panel members provided initial responses to the questions within his or her topics to review (outlined in the reading list provided by NOAA)
- As there was some overlap in these questions, there was also some overlap in the responses of individual Panel members
- Initial responses shared among the Panel for further feedback, and consistency checks

5. Questions to NOAA/DFO

- The Panel provided a list of short-term questions to NOAA/DFO within 2 weeks of Workshop 1, based on discussions held during the workshop
- Questions were predominantly related to analytical methods, could be answered quickly and would help the Panel better understand past work prior to providing its feedback to NOAA/DFO

6. Participant Feedback

- Workshop participants were given 2 weeks to submit feedback on the presentations they had seen at Workshop 1
 - These responses have been compiled in a separate document, along with discussion points raised at the actual workshop, to be provided to NOAA/DFO
 - These responses were also provided to the Science Panel
7. **Revised Responses**
- The Panel reviewed the new information from NOAA/DFO and the feedback/responses from participants
 - The Panel revised their initial responses based on this new information, as appropriate
8. **Prioritization of Recommendations**
- All recommendations across all topics reviewed by the Panel
9. **Finalization of this Document**
- ESSA synthesized the Panel's responses into this document
 - Submitted to NOAA/DFO steering committee

1.3 Document Outline

The response to each topic includes two sub-sections

1. Key Questions and Preliminary Responses
 - Responses to the questions posed to the Science Panel
 - As noted above, our impressions and responses to questions in this document are preliminary. Further written information is expected prior to or at Workshop 2 which could lead to substantial changes in our evaluation of the evidence.
2. Information and Analyses Recommended prior to Workshop 2
 - **Information Requests** for details on certain issues or topics, especially further explanation regarding analytical methods, models and data
 - **Recommended Analyses** to be completed prior to Workshop 2, if feasible. This includes recommended improvements to existing analyses and new approaches.
 - **Longer Term Recommendations** include recommendations that could not feasibly be completed prior to Workshop 2 but will still be useful for addressing key questions.
 - **Prioritization** – We have given each of the information requests and recommended analyses a priority ranking (low, medium, high). Rankings are based on how useful the anticipated information or results will be (both for the Panel's evaluation and for advancing the understanding of this issue) and not on their ease of completion. We have ranked some requests as low priority but have noted that they could be easily done. All items associated with FRAM are ranked "high" since FRAM seems central to so many of the analyses presented. Longer term recommendations are not ranked at this stage, though the Panel will do so in its final report.

Finally, this report uses the American spelling of words (we flipped a Canadian loonie, and lost).

2.0 STATUS OF KILLER WHALES

2.1 Key Questions and Preliminary Responses

Review the available information on census and population structure, the species status and recovery criteria, historical abundance and carrying capacity of Southern Residents as well as information about Northern Residents.

1) What ecosystem considerations and/or trends might be relevant, including environmental carrying capacity questions?

The basic problem is that the SRKW have such a small population size, If there were 10,000 of them their growth rate (which appears to be positive) would not be of concern.

So we must ask: Why is the population size so small? and What are the implications of this small size? Given the current abundance of Chinook, it would simply not be possible for the resident killer whales to maintain a much larger population size and eat primarily Chinook salmon.

Prior to European impacts, there would have been many more Chinook around, and there could have been more Chinook specialist resident killer whales.

On the other hand, given the lack of winter diet data, the decline of Chinook in the diet of SRKW in the fall, and the much more varied diets of other resident killer whales one does have to doubt if Chinook make up the major diet in the winter.

So why is this population so small? Hypotheses include:

1. Decline in Chinook, especially as a result of European contact
2. Competition with Northern residents, for space and or food
3. Competition for food with expanding seal and sea lion populations or other species

Estimates of total Chinook consumption over time from seals and sea lions would be useful especially when compared to Chinook harvest.

One does wonder why the southern residents don't hang around the mouths of the Columbia river, and perhaps San Francisco Bay during the Chinook migrations – the number of Chinook migrating into those systems is comparable to the Salish Sea (is it not?).

Other ecosystem issues.

It may be that Chinook and killer whales are both affected by the same environmental conditions with no causal link from Chinook to killer whales. How do we determine if there is a causal link?

2) Based on your expert opinion, what can we learn from evaluating the similarities and differences between Northern and Southern Residents

We need a bit more structured comparison of the demographic parameters of the northern and southern residents, and the relationship between these two populations and other factors, especially Chinook abundance.

It appears from material presented in the workshop that the mortality rates were roughly the same, the major difference between the two populations is the birth rates, almost twice as high for the N. Residents.

If this difference in birth rates is the key difference, we have to ask why do N. Residents have a higher birth rate (or early calf survival).

We need a comparison of the relationship between Chinook abundance and birth rates across the two populations. Ward et al. 2009 showed the same basic relationship between Chinook abundance and reproduction for N. and S. residents – thus it isn't the Chinook abundance that explains the difference. That work does need repeating across a range of measures of Chinook abundance.

We definitely need the plot of the likelihood of population growth rate for the N. Resident and S. residents to see how different they are (i.e. Section 5).

2.1 Information and Analyses Recommended prior to Workshop 2

Information Requests

- Explore the different hypotheses of why the SRKW population is so small
 - Another hypothesis is that the population has simply always been small. Is it possible to use genetics to investigate this hypothesis?
MEDIUM-HIGH
- How does the density of SRKW compare to the densities of KW in other areas – NRKW, Alaska, other? Density might not be the ideal metric – are there other useful metrics to compare different KW populations?
MEDIUM-HIGH
- What are the legacy effects of removals for the aquaria trade (also explored in Section 5)?
 - Some of this analysis has possibly already been done?
MEDIUM-HIGH
- What else is eating Chinook and how much are they eating?
 - The Panel would like to see estimates of Chinook consumption by other marine mammals over time to provide context for the consumption of Chinook by KW.
MEDIUM-HIGH

Recommended Analyses

- Project future population trends based on the current age-sex structure of the population
HIGH

- Structured comparison of the demographic parameters of the northern and southern residents, and the relationship between these two populations and other factors, especially Chinook abundance.

MEDIUM-HIGH

- Compare the relationship between Chinook abundance and birth rates across the two populations, as further described under Question 2.

MEDIUM-HIGH

3.0 FEEDING HABITS OF KILLER WHALES

3.1 Key Questions and Preliminary Responses

Review the available information on distribution, diet, food energy value of prey, daily prey energy requirements of Southern Resident Killer Whales

1) Are the methods used to estimate the SRKW diet (including species, Chinook salmon stocks, and Chinook salmon age/size) scientifically reasonable given the available information? Do you have any suggestions to improve the methods?

Diets of SRKW have been determined from floating scales and tissue recovered after a feeding event has occurred, and from the stomach contents of dead whales and the prey DNA in fecal samples. These methods are solid and are state of the art. However, sampling is concentrated in the summer months, with little or no coverage in the winter months.

The majority of the data show that resident killer whales have a preference for salmon, particularly large Chinook which appear to account for >80% of the diet from May-September. The small numbers of samples obtained during the winter suggest a greater reliance on chum salmon and on demersal species.

There appears to be some bias in diet determination associated with the methods used. For example analysis of floating scales and tissues collected in Puget Sound from October to January suggested that SRKW were primarily eating chum salmon. However, the DNA analysis of feces recovered at the same time showed that killer whales were eating a much wider range of species that included ling cod, Dover sole, halibut and greater amounts of Chinook. Chum was still a very important part of the diet, but was less important than using only the floating scales and tissues first suggested. Thus it appears that the scales of some species are less likely to become dislodged and float to the surface than for others.

The general conclusion that SRKW consume primarily large Chinook salmon (ages 4 and 5 y) is reasonable and supported by the available information. Further refinement of the methodologies and sampling designs employed to date are likely to show a more complex and diverse diet related to age, sex, pod and time of year than currently recognized. However, further diet studies are unlikely to change the fundamental finding to date that Chinook are the most important component of the SRKW diet.

Possible refinements of methodologies and sampling designs that should be considered to improve the diet information include:

- Fecal samples are more likely to better reflect what killer whales have eaten than are floating scales and tissue. DNA analysis can identify species consumed and have the

potential to estimate quantities consumed as well. They can also be used to identify which whale the sample came from. Thus greater effort should be put into collecting fecal samples. Using dogs to locate fecal samples would seem to have the potential to increase sample sizes.

- Fecal samples can provide a more accurate description of diet, but may not provide information about the sizes and ages of prey unless scales and bones are also passed. Thus skimming of scales and tissue from the water can provide useful supplementary data on dietary preferences.
- Diet data for SRKW should be broken down by pods and by age class (i.e., adult males, adult females, and juveniles).
- Diet data are needed for an entire year. Only J pod regularly uses the inside waters throughout the year. Effort should be extended to collect diet information for J pod during 4 seasons (Spring, Summer, Fall and Winter).
- Approximately 70 samples are likely to be required by season to accurately describe diet (Trites and Joy 2005). A sampling design should be implemented with a coordinated effort to collect the necessary numbers of samples.
- Diet data are also needed for K and L pods when they are not using inshore waters. Obtaining such data may first require tracking data to know when and where samples are likely to be collected.
- Captive feeding experiments with killer whales should be undertaken to verify the DNA analyses and identify potential biases (e.g., whether recovery of DNA is affected by digestibility of prey types, or whether the type of diet affects the likelihood of a scat floating).

2) Are the methods employed to estimate the daily prey energy requirements of the SRKW scientifically reasonable given the available information? Do you have any suggestions to improve the methods?

The modeling approach used to estimate the food requirements of SRKW is reasonable and consistent with the models that have been developed for other species of marine mammals. The reliability of the model estimates will be improved as better estimates are obtained for the model parameters. Most notably:

- Growth curves (i.e., mass at age) can be updated with additional data from photogrammetry or other sources.
- Activity budgets are unlikely to remain constant throughout the year. Dive depths and swimming speeds may be greater when SRKW are out of the Salish Sea.
- Consideration should be given to calculating an energy budget for summer and another for fall, winter and spring combined.
- Costs of pregnancy and lactation influence the food requirements of animals and should be accounted for in future bioenergetic models of SRKW.

- Captive killer whale studies could be undertaken to obtain better estimates for some model parameters. Feeding records and measures of body condition could also be taken to validate model estimates and gain insights into seasonal changes.

3) Based on your expert opinion*, what level of confidence would you assign to the conclusion that, during the May-Sept time period in the Salish Sea, the SRKW have a diet consisting largely of Chinook salmon?

All of the available data consistently point to Chinook salmon being the primary prey of SRKW in the Salish Sea from May-September. While there are likely some differences in the relative importance of Chinook between juveniles, adult males and adult female killer whales as shown for the NRKW, the small differences would not change the broad conclusion. Similarly, there appears to be a shift late in the season when chum appear to be of equal if not greater importance to SRKW.

4) Based on your expert opinion*, what level of confidence would you assign to the estimate of the distribution of age 3, 4 and 5 Chinook in the SRKW diet (May-Sept, Salish Sea)?

Data and analysis presented by NMFS and DFO were consistent with each other in showing that resident killer whales are selecting larger fish on average than are present in the Chinook population. The ability to reconstruct the ages and sizes of salmon from scales has been validated by fisheries biologists and has been appropriately applied to determine the age and size distribution of Chinook salmon eaten by killer whales.

5) Based on your expert opinion*, what level of confidence would you assign to the conclusion that the SRKW's coastal diet largely consists of salmon? Of Chinook salmon?

The numbers of diet samples taken during winter in offshore waters is too low to be confident that SRKW continue to specialize in eating Chinook or other species of salmon during winter. L pod had higher DDT/PCB ratios suggesting that they feed further south than J pod. This also suggests that L pod potentially consumes greater amounts of groundfish. DNA analysis of fecal samples collected during winter in Puget Sound showed a broad diet (compared to summer) consisting of chum, Chinook, ling cod, dover sole, and halibut.

6) Do you have specific suggestions to address key assumptions and uncertainties?

The biggest uncertainties are associated with 1) a lack of diet data during winter, 2) knowing whether all three SRKW pods consume the same diets, and 3) the potential to identify salmonids more readily than groundfish by relying too heavily on recovering scale samples on the surface. These uncertainties can be addressed by:

- Breaking and presenting the available diet data by pods and age and sex classes (i.e., adult males, adult females, and juveniles)
- Putting more emphasis on collecting and analyzing fecal samples using a coordinated sampling design to obtain seasonal diet samples from J pod (i.e., spring, summer, fall and winter).

- Diet data are also needed for K and L pods when they are not using inshore waters, but will likely first require tracking data to know when and where dietary samples are likely to be collected.
- Captive feeding experiments with killer whales should be undertaken to verify the accuracy of the dietary techniques and to provide data to better parameterize bioenergetic models.

3.2 Information and Analyses Recommended by Workshop 2

Information Requests

- Diet data for SRKW broken down and presented by pods (J, K, and L), age classes (adult males, adult females, and juveniles) and seasons (spring, summer, fall and winter). Seasonality within the diet data is the highest priority. What is known about K and L pods during the winter?

LOW – but easily done

Recommended Analyses

- Comparison of diets determined from fecal samples and prey remains (scales and tissue). Data from Puget Sound were presented by NMFS at the workshop; this presentation suggested that a proper comparison may already have been done. Such an analysis would help to assess the reliability of interpreting diet from floating scales and tissues.

MEDIUM

Longer Term Recommendations

- Can feeding records from Aquariums be analyzed to assess whether the energy needs of killer whales change seasonally?

4.0 FISHERIES THAT MAY AFFECT PREY AVAILABILITY

4.1 Key Questions and Preliminary Responses

Review the available information on fisheries that may affect prey availability

1) Do any parts of these data need further clarification?

The fishery data consist of time-series of either (i) Chinook salmon abundance generated via the FRAM approach, or (ii) indices of Chinook salmon abundance generated via the CTC model. These models and their input data are quite different and each was presented independently in the workshop. A clearer presentation of the differences is important because the models are used in complex, and sometimes contradictory analyses. For CTC Chinook indices, for example, Ward et al. (2009) model selection criteria (i.e., for fecundity relationships to Chinook abundance) favor a stock-specific CTC index of WCVI Chinook abundance over an aggregate coastwide CTC index. In a workshop presentation, Ward later showed that FRAM abundance is also correlated with fecundity, although not as well as the CTC model index for WCVI Chinook. In the same presentation, Ward shows that FRAM abundance is not correlated at all with SRKW survival. The MS Powerpoint file provided by Wade (2007) showed that at least three other CTC Chinook indices were better than WCVI for explaining changes in SRKW survival rates. Ford et al (2005) show that SRKW mortality is closely correlated to a broad-scale CTC Chinook index, but apparently, this correlation is not as strong based on more recent data. It is not clear whether this range of results are just a random outcome of testing many abundance datasets against multiple response variables, or whether alternative abundance covariates are actually biologically different.

Initial analyses of SRKW fecundity and survival relationships to Chinook abundance were based on various CTC model Chinook indices; however, the final assessments of prey ratios and extinction risk (via population dynamics models) use Chinook abundance outputs from FRAM. Presumably, this is because FRAM is better able to reflect the stock-specific impacts of the proposed Puget Sound Chinook management plan on Chinook salmon available to SRKW. **Figure 1** shows that FRAM abundance (thick black line) is actually quite different from most CTC Chinook indices.

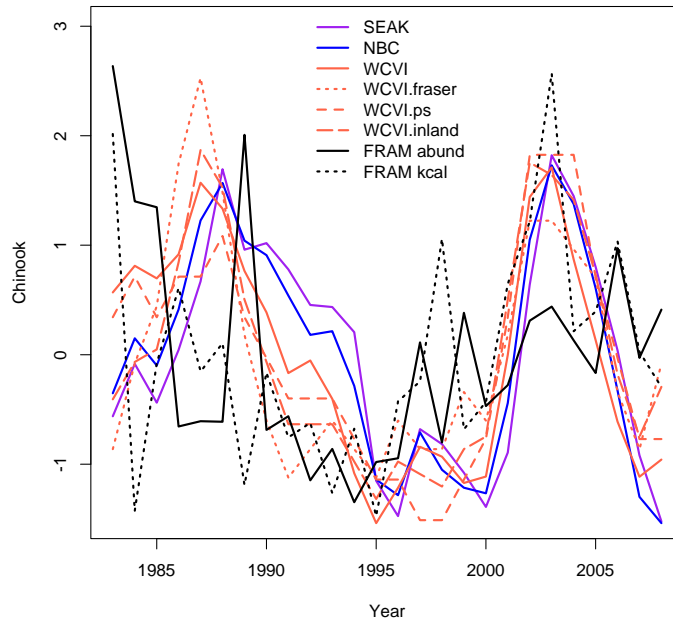


Figure 1. The suite of Chinook salmon abundance indices tested for correlation with fecundity and survival rates of SRKWs.

The difference between FRAM Chinook abundance and indices derived from the CTC model requires more critical evaluation than has been provided so far especially given that FRAM, not CTC, abundance indices are being used in the Biological Opinion. As described above, abundance indicators from both models have been used in model selection analyses, but there is little discussion of the differences between the abundance indicators themselves. Why would FRAM and CTC abundance indicators be so similar in their correlation with fecundity, yet be so different in correlations to survival?

Based on FRAM analyses, the general conclusion so far is that within a season (i.e., not accounting for long-term impacts of fisheries on total Chinook abundance) fisheries probably have a relatively small effect on Chinook available to killer whales. This conclusion seems predicated on several FRAM assumptions, including:

All preferred size/age ranges of Chinook are available to SRKWs at all times during the year. This follows from FRAMs single-pool assumption;

Natural mortality varies by age, but is constant among FRAM seasons (i.e., Oct-Apr, May-June, Jul-Sep) and years. This implies that natural mortality is not dependent on Chinook consumption by SRKWs or increasing NRKWs and other marine mammals;

Natural mortality, fishing mortality, "potential" mortality caused by SRKWs operates independently and sequentially within FRAM seasonal time periods;

Both natural and fishing mortality processes are modeled in FRAM via fixed proportional rates that are independent of Chinook abundance. For example, the percentage of age-5 Chinook dying of

natural causes is a constant 10%/year regardless of Chinook or marine mammal abundance. Fisheries are modeled in a similar way using fixed exploitation rates specific to each year, season, and area. In fisheries jargon, these assumptions lead to "input controlled" mortality processes in which annual mortality rates are roughly proportional to the amount of total feeding activity by whales (i.e., # Chinook eaten per whale x # Whales) and fishing effort for fisheries. It is well-known that input controlled processes maintain compensatory survival (e.g., survival rate is unaffected by Chinook abundance) and therefore maintain stability of harvesting and predator-prey systems.

In reality, few fisheries have been managed successfully using purely input controls because harvesters rapidly adapt their search effort, efficiency, etc. to achieve similar **catch levels** under different management regimes rather than maintaining similar exploitation rates. There is also strong evidence that predation processes are non-linear wherein consumption rates per predator can be relatively constant over a wide range of prey abundance (e.g., Holling Type II functional response with handling time limitations). Also, if killer whales (pardon our ignorance if we're wrong here) have relatively strict consumption requirements, then perhaps they too adjust feeding behavior over the year to maintain relatively constant **total consumption** rates (e.g., # Chinook per year per whale). In any case, it is possible that either or both catch levels in fisheries and consumption rates by whales don't adjust very quickly to changes in Chinook abundance. Any lack of adjustment leads to depensatory survival processes in which mortality rates actually increase with decreasing abundance. Such non-linear processes are destabilizing in both fisheries and predator-prey systems. The point to all this is to clarify how we (and some workshop participants) see the combined impacts of fisheries and marine mammals on Chinook salmon abundance and availability to SRKWs as probably being much more complex than assumed in FRAM calculations. This also provides the basis for recommended further analyses (see below) using a "competing risks of death" modeling approach.

4.2 Information and Analyses Recommended by Workshop 2

Information Requests

- The flow diagrams and responses provided by L. Lavoy after the workshop (i.e., in response to follow-up Q10) provide useful details as well as a graphical overview of FRAM abundance definitions, calculations, and input data. We strongly encourage more extensive use of such graphical tools in upcoming workshops rather than complicated explanations accompanied by bulleted lists. (note that the symbols used should be more clearly defined if they to convey their meaning in the flow diagram).

HIGH

- Understanding the spatial and temporal structure of FRAM is important, especially in trying to understand how FRAM and CTC-based indices differ in their potential relevance to SRKWs. It might be helpful to show additional flow diagrams for "Model Pre-Terminal Fisheries" and "Model Terminal Fisheries", in particular showing what specific Chinook stock groups are present within each fishery type and season. This might provide indications of where/when FRAM and CTC models differ and therefore, whether these differences increase/decrease the possible relevance to SRKWs.

HIGH

Recommended Analyses

- **Clarifying the differences between CTC and FRAM models** requires a side-by-side comparison of:
 - a. The two model structures, key assumptions, input data, and output. This could be done using flow diagrams as suggested above;
 - b. Sensitivity of each method to errors in catch and escapement input data (as noted by some participants in the workshop). Specific questions include
 - - What is the range of error in any particular FRAM or CTC estimate?

HIGH

- **Assess interdependencies among fishing, natural, and KW predation mortality using continuous catch equations.** The Panel questioned the validity of FRAM's discrete approximation to apportioning total mortality among southern vs northern resident killer whale consumption, various types of fisheries, and "other" mortality such as that owing to other marine mammals. If killer whales (both SR and NR) impose high mortality rates on their preferred sizes/ages of Chinook, then FRAM approximations may give erroneous predictions about the impact of fisheries. If killer whale consumption rates (# Chinook consumed per whale) and population sizes are relatively constant, but account for a substantial fraction of Chinook mortality, then total mortality of Chinook probably varies considerably from year to year. Examining such interdependencies among sources of mortality can be done using standard catch equations or competing risks of death model, i.e.,

$$C_j = \sum_a N_a \frac{S_{a,j} F_j}{Z_a} [1 - e^{-Z_a}]$$

where j is a mortality component index (e.g., 1=fishery, 2=SRKW, 3=NRKW) C_j is the total number of Chinook caught in fisheries or consumed by killer whales, N_a is the abundance-at-age of Chinook available, $S_{a,j}$ is the selectivity-at-age a , F_j is the force of mortality caused by component j (i.e., a fishery or whale population), M is natural mortality from sources other than fisheries and whales, and Z_a is the total mortality rate at age a , i.e.,

$$Z_a = M + \sum_{j=1}^J S_{a,j} F_j.$$

A static form of these equations (i.e., no temporal dynamics) can be used to examine, for example, how the fraction of total Chinook mortality caused by killer whales (or fisheries) varies with (i) SRKW as well as Chinook abundance, (ii) the magnitude of natural mortality and proportion attributable to whales, (iii) fishing mortality rates, (iv) abundance of

NRKWs, assuming they make up some fraction of M as well, (v) Chinook availability to whales (via proportion of N_a within whale habitat), etc.

Fisheries and whales can be modeled independently via different means using the above model. For example, if fishing mortality rates are the driving variables for fisheries, then values F_j are input for fisheries, while if only total consumption is known (or assumed) for whales, then C_j can be input for whales. The equations can then be solved for the unknowns, i.e., C_j for fisheries and F_j for whales.

We created a preliminary version of this model to examine the types of information that could be provided. For example, Figure 2 shows how the SRKW "force of mortality" ($F_{j=2}$) on age-5 inland Chinook changes with the assumed non-whale natural mortality rate and total age 3-5 inland Chinook abundance assuming that SRKW-derived mortality is additive to fishing-, natural-, and NRKW-derived sources of mortality.

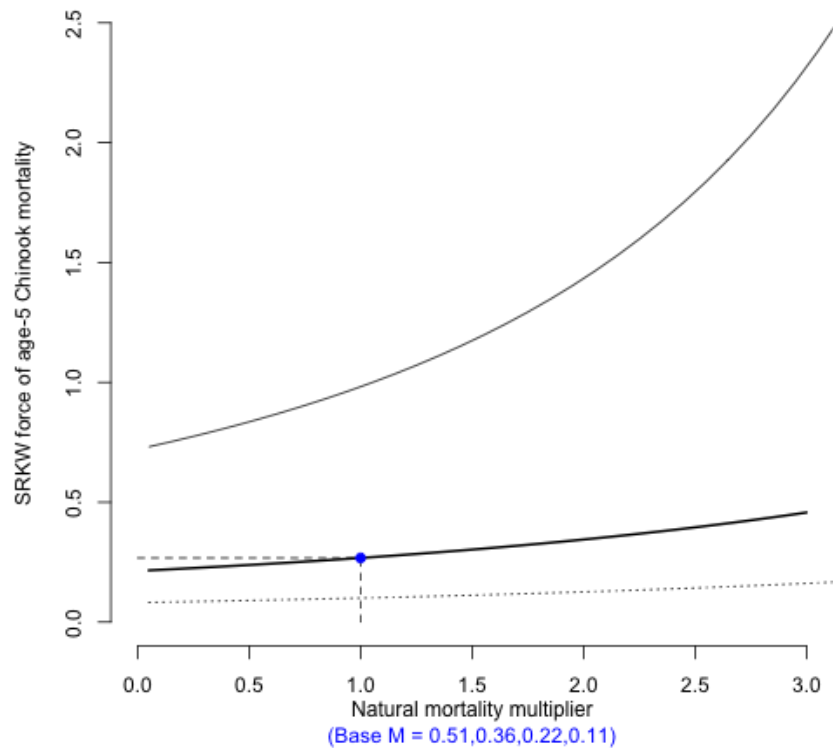


Figure 2. Changes in the force of mortality caused by SRKWs ($F_{j=2}$) on inland age-5 Chinook as a function of natural mortality rate and total age 3-5 inland Chinook abundances of 6 (dotted), 2.5 (thick solid), and 1 (thin solid) million fish. Selectivity-at-age is 0,0,0.3,1.0 for ages 2-5, respectively. Each line is the result of solving the catch equations given total consumption of 50,000 (fishery), 200,000 (SRKW), and 100,000 (NRKW). Natural mortality multiplier values to the left of 1.0 represent cases where SRKW consumption makes up an

increasing fraction of natural mortality. Base M represents the age-specific instantaneous mortality rates (for ages 2, 3, 4, 5) corresponding with FRAM's age-specific mortality probabilities (0.4, 0.3, 0.2, 0.1).

The results suggest that at abundances of 2.5 and 6.0 million Chinook, SRKWs exert a similar force of mortality regardless of whether they are major or minor contributors to total Chinook mortality. This implies little need for the whale to make major changes in feeding behavior to achieve similar consumption rate. On the other hand, at Chinook levels below 1.0 million fish, SRKWs must exert a force of mortality that is not only substantially greater, but also increases non-linearly as other sources of mortality increase (e.g., marine mammals other than SRWK and NRWK).

The above discussion is meant to sketch the types of analyses that could be done. It does not actually model Type II functional response behavior of whales, because that would require a numerical solution of the catch equations. Similarly, we made what seemed like sensible assumptions for parameter values given our current understanding. Regardless, this simple result suggests that nonlinear interdependencies among actors (i.e., fisheries, whales, other marine mammals) influencing relationships between SRKW growth rates and Chinook abundance could arise under reasonably plausible circumstances. Such relationships need to be analyzed in trying to establish causal linkages between fisheries and SRWK population growth rates.

HIGH

- **Are there alternate approaches to the FRAM model?**

- NOTE: This recommendation comes from the questions regarding FRAM that have arisen in under multiple different topics.
- There are many questions with how FRAM works, including its structure, uncertainties, process flow, output, etc. Consequently, the Panel has concerns regarding some of the results of the model (which may be resolved by improved understanding of how the model functions).
- It is evident that FRAM is a very difficult model to understand for everyone but a few individuals. Consequently, the Panel has concerns with the ability to communicate results from such a “black box” to the broader community that has interests in the results of these analyses. It is difficult to be transparent when understanding of the model is generally limited.
- The NMFS analyses are fundamentally connected to FRAM, but is this necessary? Are there other options? Could other options be developed over the longer term? It was acknowledged at the workshop that FRAM is already being “pushed” well beyond its original design limits. Given its complexity and all of the issues/questions raised here and by participants, is it more beneficial to continue pushing it further, or to start exploring/developing alternative approaches?

- The Panel would like to see a review of alternate stock reconstruction methods and a discussion of the feasibility of adapting or developing other approaches. Is FRAM really the only feasible option?

MEDIUM-HIGH

Longer Term Recommendations¹

- Investigate approaches to incorporating inter-annual changes in SRKW and NRKW consumption into FRAM abundance calculations. As shown in Figure 2, increases in marine mammal consumption of Chinook could have important consequences for SRKW feeding processes, especially during periods of low Chinook abundance.
- How much of the error is due to imprecise escapement enumeration, errors in effort scalars, selectivity and VonB growth rate assumptions², as well as errors in arrival timing to terminal areas?
- How much of the interannual variability in FRAM abundance is due to errors in input data and scalar parameters associated with base period calibration (e.g., abundance spikes in 1989 and the mid-1990s)?
- How do errors in abundance estimates propagate over time within and among years?
- -How do changes to the operation and magnitude of fisheries, as well as changes in escapement enumeration programs, affect the confidence in temporal trends in abundance (i.e., for correlation with fecundity and survival)?

¹ These recommendations (of variants thereof) are probably not realistic for Workshop 2, but should perhaps be discussed for their potential contribution in the future.

² von Bertalanffy growth parameters estimated from CWT catch data (as noted in FRAM documentation) may be seriously biased towards faster growing fish.

5.0 RELATIONSHIP BETWEEN CHINOOK ABUNDANCE AND KILLER WHALE POPULATION DYNAMICS

5.1 Key Questions and Preliminary Responses

Review the available information on demographic modeling, the role of nutrition in individual growth and condition, and available and emerging methods to investigate body condition

1) Are the methods employed to evaluate the relationship between salmon abundance and SRKW (and/or NRKW) fecundity, survival and population growth scientifically reasonable? Do you have any specific suggestions to improve the methods?

Establishing reliable evidence for effects of salmon abundance on killer whale survival and fecundity is a necessary step for any further consideration of managing fisheries to enhance the viability of killer whale populations. Thus, this relationship is truly pivotal to the problem at hand. The methods for evaluating relationships between salmon abundance and vital rates of SRKW are reasonably standard, including three separate regression analyses conducted by Ward, Ford, and Wade. The three analyses reached somewhat different conclusions. Ward found that both survival and fecundity were influenced by salmon abundance, while Ford and Wade found an effect of salmon abundance on survival but not fecundity. The analyses used different indices of salmon abundance. Ward and Wade used information-theoretic methods to evaluate the strength of evidence in data for the different indices. These methods add substantial value to the analysis by allowing us to conclude which models are best able to make short-term predictions.

All three analyses suffer from failure to include uncertainty in the indices of abundance used as independent variables. This is problematic because the assumption that covariates are measured without error underpins all linear regression. The failure to account for these uncertainties means that the ostensible effects of salmon on SRKW are estimated with erroneous precision, leading to false certainty about those effects. In technical terms this means that the confidence envelopes on regression coefficients are too narrow, raising the possibility that all of the estimates of slopes overlap 0.

Other potential ambiguities in interpreting this relationship need to be addressed, particularly the possibility that changes in vital rates might be due to transient effects of changes in age classes or other demographic effects resulting from effects of removals during the 1960's and 70's, discussed below.

2) Based on your expert opinion, are there additional analyses that could be conducted on the SRKW population or other resident killer whale populations to better understand the relationship between salmon abundance and killer whale survival, fecundity, and population growth?

Future work must include uncertainty in the independent variables in all estimates of the effects of salmon abundance on killer whale vital rates. Mathematical analysis of the projection matrix for killer whales conducted by Caswell (1996) showed that the population growth rate will be far less sensitive to variation in fecundity than in adult survival. However, the data presented in the current analyses also show, as expected from theory and previous empirical work, that fecundity tends to show far greater annual variation than survival, so both vital rates are important to the long term outlook for the population. Ward (2010, unpubl) was the only analysis to extend effects of salmon abundance on vital rates to population growth. The reliability of his work was enhanced by a sophisticated, integrated treatment of uncertainties arising from model selection and parameter estimation, including unknown sex ratios at birth. However, the analysis suffers from failure to assess uncertainty in salmon abundance as described in the previous section. Concerns were raised by the Panel about autocorrelation in the data and the possibility that survival and fecundity data (0-1's) were not independent.

Several responses to the September workshop amplified this point and some suggested that including errors in independent variables would be problematic statistically. However, hierarchical methods provide a straightforward way to include these uncertainties in logistic regression if biases and observation variance in the "x's" can be properly identified (Clark, 2007; Clark and Bjornstad, 2004)

However, it is not clear how bias and variance in the independent variables might be quantified because these variables are formed from model output and from indices rather than from absolute measures of salmon abundance. Thus, it is not possible to use sampling error to assess observation uncertainty. Estimating biases in estimates of the x's is problematic because there appears to be no calibration relationship between measurements of salmon abundance and indices or model output representing abundance. In the absence of estimates of sampling error and calibration relationships, the only recourse is to examine sensitivity of the relationship between killer whale vital rates and salmon abundance using simulation. We can be sure that errors in the x's exceed 0, assumed in the current analysis. The Panel would like to see how including plausible errors in the x's might affect the conclusion of a correlation between salmon abundance and killer whale survival and fecundity.

Responses to the Panel included the idea that demographic effects from removals for the aquaria trade in the 1960's and 70's may account for the slower than expected population growth. The Panel agrees these legacy effects should be thoroughly explored because changes in demography, rather than forcing from food supply could explain changes in vital rates. It is not uncommon for demographic processes in populations to produce effects on population growth rate that are wrongly attributed to external causes (Bonenfant et al., 2009).

3) Are the methods employed to evaluate the potential for nutritional stress in the SRKW population scientifically reasonable? 4) Based on your expert opinion, what level of confidence would you assign to the conclusion that the SRKW exhibit signs of nutritional stress? Of cumulative effects that include lower than optimal nutrition?

The Panel agreed that detailed studies of energetics of killer whales in relation to energy availability were interesting scientifically and were useful in establishing a plausible, mechanistic link between vital rates of killer whales and abundance of salmon. However, we also agreed that these studies were not useful in formal statistical analyses of responses to killer whales to variation in salmon abundance.

5) Are the methods employed to evaluate the viability of the SRKW under alternative assumptions about future salmon abundance scientifically reasonable? Do you have any specific suggestions to improve the methods?

Ward evaluated the viability of the SRKW population by estimating the probability that the population would be extinct twenty five years in the future assuming different levels of salmon abundance. Estimate were obtained using three steps: 1) salmon abundance was estimated from the deterministic FRAM model; 2) the relationship between FRAM-estimated salmon abundance and killer whale vital rates was estimated using a fully Bayesian, logistic regression, and 3) regression estimates of vital rates were used in an individual-based simulation model to estimate population viability. The analysis was straightforward, but it involved many steps and is highly sensitive to assumptions on catastrophic events and the end-date for evaluating population viability. The chain of output from one model serving as input for another model raises questions about the reliability of statistical inferences that assume independent variables are observations.

6) Based on your expert opinion, are there additional analyses that could be conducted on the SRKW population or other resident killer whale populations to better understand the relationship between salmon abundance and killer whale population viability?

The population viability analysis should be re-done using a range of acceptable population sizes, not extinction. The revised analysis should calculate the probability that the future population will be below the lower limit of the acceptable range, within the range, or above its upper limit. These probabilities should be calculated using scenarios for salmon abundance that reflect achievable increases in salmon abundance—that is something like 10-20%. It would be possible to do this analysis using a Bayesian hierarchical approach, treating true salmon abundance as a latent, unobserved quantity. This approach would put the entire analysis in a coherent statistical framework and would help alleviate the problem of model output serving as model input.

The Panel agreed that it would be useful as well to examine population growth rate as an indicator of recovery in the presence and absence of interventions to modify fisheries. We suggest the following approach. Define λ as the discrete time, annual rate of increase of the population³. The Panel would like to know the posterior distribution of the current value of λ in the absence of any intervention to enhance salmon abundance (Figure 1A). This can be calculated from the superb demographic data of the northern and southern populations by estimating vital rates and associated uncertainties from the time series and then estimating $P(\lambda|y)$, where “y” is the demographic data, as a function of those estimates. In the Bayesian framework, this can be easily

³ Conventionally estimated as the dominant eigenvalue of the females-only projection matrix.

accomplished by sampling from the converged Monte-Carlo Markov chain and estimating a dominant eigenvalue for the projection matrix from each draw from the MCMC chain. It is important that this estimate incorporate demographic stochasticity, which can be accomplished in the process model component of the hierarchy.

Define λ' as a rate of increase that would be acceptable under recovery goals. The Panel would like to know the posterior, predictive distribution of λ' given reasonable assumptions for achievable increases in salmon abundance (Figure 1B). This distribution is predictive because it depends on predicting the population growth rate given assumptions about what would happen if the salmon fishery were modified. It is a posterior distribution because it is conditional on the population data.

The potential for management action to enhance population growth rate is given by the difference in the areas under the poster distribution of λ and the posterior predictive distribution of λ (Figure 1C). This is the increased probability of achieving recovery goals for population growth rate given a plausible management action. The value of this analysis is that the posterior distribution of λ (Figure 1A) represents a null model, allowing calculation of the marginal improvement in population growth rate attributable to management intervention to increase salmon abundance (Figure 1C). This has not been done in the analyses we reviewed.

The Panel would like to see this analysis for the NRKW and SRKW populations, for pods within the SRKW, and with λ treated as a random effect where the growth rate of each pod is drawn from a distribution of growth rates. The analysis should be done on females only and, if there is there is any appreciable difference in the results, for two sex models.

The Panel reviewed the analysis advocated by Shannon Knapp (Review of the Effects of Chinook abundance on SRKW Fecundity, Survival, and Population Growth) that emphasized long term projections of killer whale abundance including demographic uncertainty. The experience of the Panel suggests that properly including process variance in such forecasts means that forecasting horizons beyond 3-5 years are uninterpretable because virtually all possible outcomes are included in forecasts extending further into the future. Focusing analysis on population growth rate rather than future population size, as we recommend here, avoids this problem. Moreover, the analysis we recommend includes uncertainty about the current state and the potential that managing the fishery could meet restoration goals.

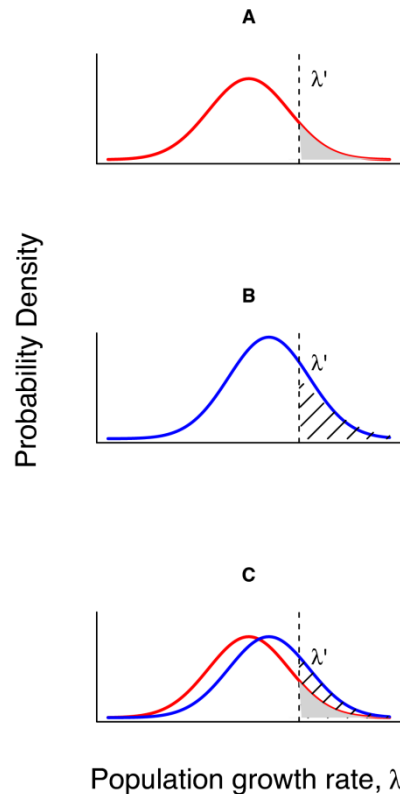


Figure 1: **A.** Posterior distribution of the current growth rate of the population estimated from the time series of demographic data. The quantity λ' is a target growth rate, which if sustained, would indicate recovery. The shaded area to the right of λ' gives the probability that the current population equals or exceeds recovery goals. **B.** Posterior predictive distribution of λ assuming increased salmon abundance resulting from some intervention. The striped area to the right of λ' is the probability of meeting or exceeding recovery goals given the intervention. **C.** Posterior predictive distribution of λ overlaid on the posterior distribution of λ . The difference in the area between the two curves above λ' (i.e., the striped area between the red and blue curves) is the effect of the intervention on the probability of meeting or exceeding recovery goals.

5.2 Information and Analyses Recommended by Workshop 2

Recommended Analyses

- Examine uncertainty in the independent variables in all estimates of the effects of salmon abundance on killer whale vital rates, as described in Question 2.

MEDIUM-HIGH

- The legacy effects of past removals for the aquaria trade should be thoroughly explored because changes in demography, rather than forcing from food supply could explain changes in vital rates

MEDIUM-HIGH

- The population viability analysis should be re-done using a range of acceptable population sizes, not extinction, as outlined under Question 6.

HIGH

- Examine population growth rate, λ , as an indicator of recovery in the presence and absence of interventions to modify fisheries, relative to a target growth rate for recovery (λ'), as outlined under Question 6.

HIGH

- The analyses above should be done for NRKW and SRKW to explore differences between the two populations.

HIGH

6.0 CHINOOK NEEDS OF SOUTHERN RESIDENT KILLER WHALES

6.1 Key Questions and Preliminary Responses

Review the NMFS and DFO's analyses of the population's Chinook needs. Based on this information

1) Based on your expert opinion*, what level of confidence would you assign to the conclusion that the SRKW prey energy requirements are within the range of Chinook kilocalories or numbers of Chinook estimated by NMFS and DFO?

The estimated energy requirements are reasonable, but rough estimates. They have been derived using the best available data, and can only be refined by incorporating better parameter estimates for such variables as body mass at age, activity, reproductive state, and basal metabolic rates. Such model refinements would improve confidence in the estimates. Nevertheless, the numbers of fish that NMFS and DFO estimate that SRKW require are within reasonable limits.

2) Do you have specific suggestions to address key assumptions and uncertainties in the analysis?

In addition to refining model parameter estimates, seasonal variability in energy requirements still needs to be addressed. Photogrammetry data could be used to address seasonal changes in body condition, and its possible relationship with seasonal changes in metabolism due to differences in dive behavior and daily activity budgets. A mismatch in seasonal prey availability with seasonal calorie requirements can have significant physiological effects on fecundity and susceptibility to disease. Photogrammetry data could be used to investigate body condition changes in years of high versus low Chinook abundance.

6.2 Information and Analyses Recommended by Workshop 2

Recommended Analyses

- Rerun the models to estimate the energetic cost of pregnancy and lactation. However, the Panel expects that the energetic costs of pregnancy and lactation, while very important at an individual level, will be minimal at a population level because at any given time, very few females in the population are pregnant or lactating. The incremental energetic costs are very small relative to the total energy to support the population. However, if there are substantial energy limitations due to prey availability, these individuals may in fact be the most vulnerable. Ultimately, the key question is whether the incremental energy demands of pregnant/lactating females are contributing to decreased recruitment, but the Panel feels that demographic analyses are a more useful approach to answering this question than the energetics approach. However, the energetics analyses are useful for understanding the mechanism by which a demographic response may be operating.

LOW-MEDIUM – but easily done

Longer Term Recommendations

- There are likely to be some useful synergies by having the photogrammetry team and energetic modelers work together to understand the seasonal changes in body condition and energy requirements, and whether SRKW are nutritionally stressed.

7.0 CHINOOK ABUNDANCE AND FOOD ENERGY AVAILABLE TO KILLER WHALES

7.1 Key Questions and Preliminary Responses

Review the analysis conducted to date

1) Are the methods employed to predict salmon abundance by stock in specific times/places scientifically valid?

- stock specific abundances are produced from FRAM, a model that has been used for decades to reconstruct stocks from catch and escapement data. This model is only vaguely documented, making it difficult to assess the validity of calculations, or their possible uncertainties, made to estimate Chinook availability to killer whales.
- KW size selectivity is key to the evaluation of what Chinook are available to whales. Results seem sensitive to the selectivity function. How selectivity plays out in winter when whales are in coastal waters (where large Chinook are possibly rare) appears to be a very important source of uncertainty in these calculations. Size- and species selectivity may be very different in winter seasons.
- the work documenting the energy density of Chinook salmon is very good and currently does not represent a substantial source of uncertainty in the overall analyses at this point. The bigger issues relate to the winter diets and size selectivity of SRKW.

2) Are there improvements to the methods you would suggest?

- FRAM and its implementation need to be more fully described (schematically and mathematically) before even a basic understanding can be gained by the Panel. Weak correlations between FRAM estimates of Chinook abundance and PSC estimates need clarification.

7.2 Information and Analyses Recommended by Workshop 2

Information Requests

- As described elsewhere in this document, more information about the structure of FRAM and its implementation is needed to assess the uncertainties/reliability of estimates of Chinook abundance. This should be written like the Methods section of a journal paper.
- The ecology of KW in winter (and spring and fall) is critical to understanding the reliance of KW on Chinook salmon. It is desirable to have a complete summary of all non-summer data about the SRKW presented. It would also be useful to know what the realm of possibility for studying the winter ecology of SRKW is.

HIGH

MEDIUM

Recommended Analyses

- See sections 4, 5 and 8 of this document, which describe analyses to assess uncertainties associated with FRAM estimates of Chinook abundance.

HIGH

Longer Term Recommendations

- To be determined after workshop 2

8.0 REDUCTION IN CHINOOK ABUNDANCE AND FOOD ENERGY FROM FISHERIES

8.1 Key Questions and Preliminary Responses

Review the analytical approach from the opinion and NMFS report on fishery profiles

1) Are the methods employed to predict the reduction in salmon abundance by stock in specific times/places scientifically valid?

The methods used to predict the reduction in salmon abundance due to fisheries have considerable conceptual appeal, but the Panel believes that they are (a) flawed from a theoretical perspective, and suffer from (b) weakly specified and/or motivated SRKW “size selectivity” functions and ocean natural mortality rates, and (c) poorly understood matches between SRKW distribution, particularly during winter, and distribution of associated salmon stocks, including abundances of chum salmon. We briefly sketch our concerns below.

a) Theoretical flaws – The accounting model used by FRAM first reduces run reconstruction estimates of pre-fishery ocean stock/age-specific abundance by (a) assumed natural mortalities (presumed to include killer whale predation) followed by (b) ocean fishing mortalities. Three time periods break up the year’s fishing and mortality. Differences in numbers of Chinook salmon calculated to be alive for FRAM runs with and without fishing are used to calculate the “additional” numbers of Chinook that might have been available to killer whales if there had been no fishing in certain areas. This kind of sequential accounting is highly problematic for two reasons. First, natural mortalities are conjectured rather than estimated from CWT recovery data and, as noted at the workshop, salmon mortalities due to killer whales are included within the conjectured natural mortalities. How can it be meaningful to view the “saved fish” as those that might additionally be available for killer whale consumption when killer whale consumption of Chinook has already been included in natural mortality? Second, the FRAM accounting is also flawed from a theoretical perspective. The standard exponential fisheries mortality model ($S = \exp(-(F+M))$), which assumes that instantaneous forces of natural mortality (M) and fishing (F) are simultaneously operating, can easily be extended to additional forces of mortality (e.g., $S = \exp(-(F + M_o + M_{kw}))$), where M_o denotes a force of natural mortality excluding killer whales and M_{kw} denotes the force of mortality associated with killer whales (expanded further in section 4). These more generalized models are called “competing risks of deaths models” and provide an appropriate theoretical framework within which to assess the probable impact of elimination of fishing as a cause of death.

The current FRAM accounting essentially assumes that all fish that would have been caught in closed fisheries instead survive to become available to killer whales. That conclusion is, from a theoretical perspective, false because all three forces of mortality are simultaneously competing for Chinook. The general effect of failure to formulate this kind of problem as a competing risks of death model is that the reduction due to closure of fisheries (= presumed benefits to killer whales in terms of additional Chinook assumed available for killer whales) will be exaggerated as compared

to the calculation that would be made from a competing risks of death model. Thus, more “benefit” would be computed than would be expected to be realized under the competing risks of death model. The degree of difference between the FRAM accounting and a competing risks of death model depends on the relative sizes of the three forces of mortality identified above.

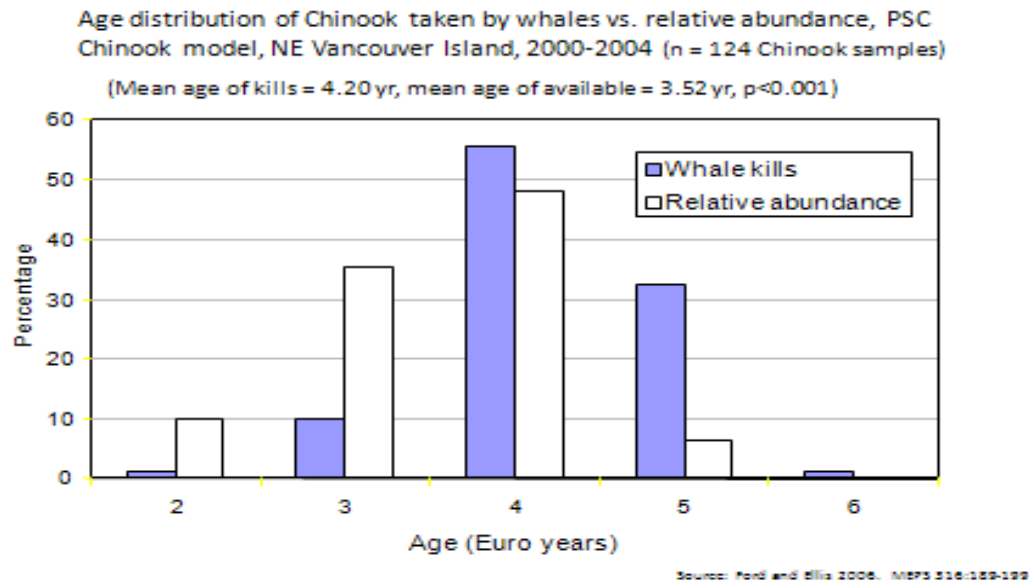
b) Poorly understood ocean natural mortality of salmon – as noted during our workshop discussions, and as is well known to salmon biologists who get involved with fishery management, existing guesstimates of ocean natural mortality rates of Chinook are based more on wild conjecture than on data or evidence. At best, one would have to make a number of different assumptions about the possible range of values that M_o may take on to see how sensitive results are to that key parameter.

c) Possibly inappropriate data use for fit KW size selectivity functions - Specification of the KW size selectivity function, especially as presented in Ward’s first talk, is also highly problematic, we think. Parameters of Ward’s curves appear to have been calculated via comparison of estimated FRAM ocean abundances of ages 2, 3, 4 and 5 Chinook, discounted for natural mortality and ocean fishing, as compared to the age composition of Chinook detected in KW foraging/fecal samples. Although the age composition in the diet samples seems reasonably valid (we are much less concerned about possible sampling biases after the workshop presentations than we had been prior to the workshop), the age composition of those Chinook salmon which are directly available to the SRKW populations is not known and is unlikely to be well represented by the FRAM values. In particular, we are concerned that the “availability” of age 2 fish to killer whales, especially in Puget Sound during summer, when the fish age composition data have been gathered, is much, much less than the discounted ocean abundances of “inland stocks”. Only those age 2 fish destined to mature would likely be found in the inland areas where the SRKW population feeds during summer months. Given the low tendency of many Chinook populations to produce age 2 jacks, this might be less than 10% of the discounted ocean abundance that appears used to generate the selection curve parameters.

A similar argument could be made for age 3 fish for which age-specific maturation probabilities may be less than 30% in some late-maturing stocks. Somehow, the calculations need to account for the maturity schedules of the different age classes, ideally on a stock-specific basis to account for differences in maturation schedules across Chinook stocks. We suspect that the general effect of including a very large excess of age two fish and an excess number of age 3 fish assumed “available” to killer whales is to exaggerate the degree to which selectivity seems nearly knife-edge and the degree to which SRKW preferentially hunt larger age 4 and 5 Chinook.

The most useful data presented to us concerning size-selectivity of killer whales were presented in Ford’s foraging talk and are based on Ford & Ellis (2006). For the figure reproduced below, age composition of Chinook was based on test seine fisheries in the immediate vicinity of the foraging whales. Note that the percentage age composition of age 2 fish is very small in these test fishery data, as argued above.

Selection for Chinook prey size



In Ward's first presentation (devoted to SRKW size selection of Chinook), he relied upon FRAM calculations of Chinook abundance which appear to consist of conjectured ocean abundances of immature and maturing fish within each age group. His math is probably fine, but his data sets seem seriously flawed.

Chinook scales

- 87 Chinook scales, 2004-2008
 - 11 age3 (12.6%), 42 age4 (48.3%), 34 age5 (39.1%)
- 12 FRAM "periods"
 - Oct-Apr, May-June, July-Sept
 - Each period in each year has slightly different age structure
 - Overall age comp. is roughly:
 - 60% age-2, 30% age-3, 7% age-4, 3% age-5

FRAM = "Fishery Regulation Assessment Model"

http://www.pcouncil.org/wp-content/uploads/FRAM_Overview_Final_1008.pdf

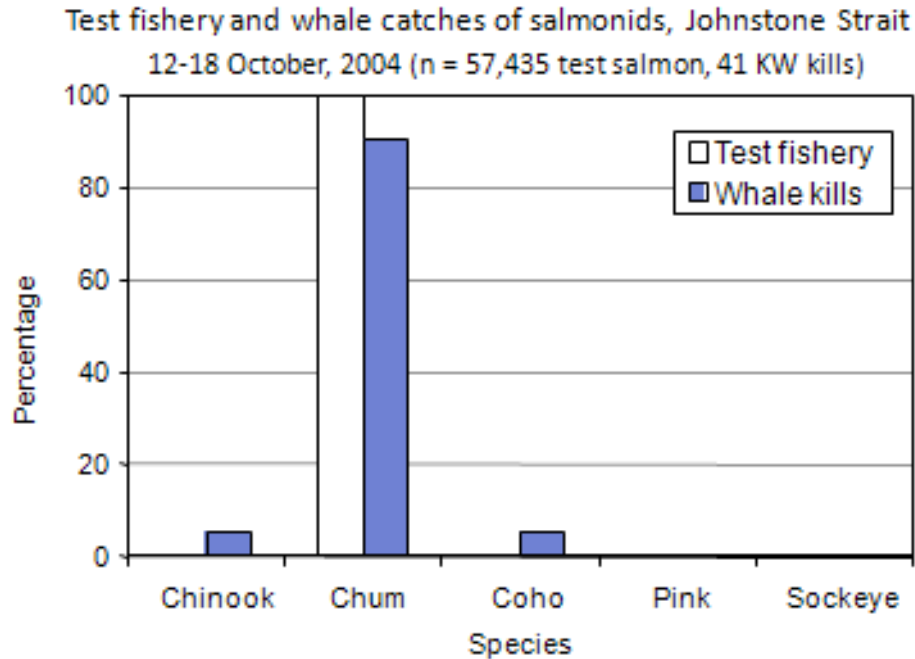
The FRAM calculations of age composition data are not appropriate for specification of a selection curve because the SRKW forage during the summer months only Chinook that are “available” in inland waters. These probably consist primarily of maturing individuals (see Ford’s test fishery data above).

d) Based on LaVoy’s response to a question from the Panel following the first workshop (“How is ‘available Chinook prey’ computed?”), we remain unclear regarding whether the “inland” and “coastal” population separation effectively addresses the issue of the likely distribution of maturing as compared to immature Chinook. It does seem that coastal populations (those spawning in coastal streams) would be unlikely to be found in the Puget Sound area where the SRKW population is found during summer months. Although it is reasonable to suppose that maturing fish from inland stocks (those spawning in streams entering Puget Sound or in the Fraser, etc.) would be found in the location of the SRKW, but it seems unlikely that the immature age 2 and age 3 fish would be present in these waters (with the exception of certain hatchery Chinook stocks that have been selected to hang around in the Sound),

As noted above in the context of size selectivity by SRKW, it seems reasonable to suppose, for most Chinook stocks, that primarily maturing individuals from “inland stocks” (as defined by LaVoy) are available in inland waters during the summer foraging period for SRKW. It is not clear to me that the FRAM model calculations, as outlined by LaVoy, account for stock-specific maturation schedules. Instead, all individuals within a stock/age group, regardless of whether or not they are immature or maturing, seem assumed available in inland waters if the stock is an “inland” type.

The apparent switch to chum salmon in September/October was dramatic in Ford’s foraging presentation, and seems of substantial significance, but seems to have been ignored in FRAM calculations and in the workshop in general. Why assume that SRKW rely primarily upon Chinook throughout the year when there is very direct evidence of prey switching that seems related to prey abundance (see figure below from Ford’s foraging PPT)? We do not understand the logic behind such a conjecture (year round reliance exclusively on Chinook), although we suppose it does put an “upper limit” on the potential importance of Chinook for SRKW.

Chum predominant prey species, mid October



Source: Ford and Ellis 2006. MSEP 516:129-139

2) Are there improvements to the methods you would suggest?

As noted above, calculations could be improved by:

- Adoption of a competing risks of death modeling approach, using a variety of conjectured values for M_o and M_{kw} and using associated values of F that are consistent with M_o and M_{kw} . This kind of model would give a more realistic notion of potential loss of prey to SRKW due to competition from ocean fishermen.
- Use of size selection curves that are based on the data presented in Ford's presentation (based on Ford and Ellis 2006) for which KW prey sampling was carried out in the same area as test seining so that the age composition of "available Chinook" reflected fish actually in the immediate vicinity of SRKW (and likely consisting primarily of maturing fish during the summer period).
- Modification of FRAM abundance calculations so as to account for stock-specific maturity schedules so that summer abundances of "available" Chinook consist primarily of maturing individuals which, on average, have an older age composition than the overall ocean abundance (which includes substantial numbers of immature fish that presumably remain offshore).

d) Rethink the logic behind an assumption that SRKW rely primarily upon Chinook salmon throughout the year. What is the basis for this assumption? Isn't it at odds with the striking shift to chum salmon in Sept/Oct that was documented by Ford and Ellis (2006)?

8.2 Information and Analyses Recommended by Workshop 2

Information Requests

- Can FRAM apply age- and stock-specific maturation probabilities to “global” abundances so as to generate more useful measures of Chinook that might actually be available to SRKW? At the workshop, Jim Scott (WDFW) suggested that this might be possible.
- A related question is: Is there any way to relax the untenable assumption that ocean and inland distributions of stocks remain constant over the three FRAM time periods, which is at odds with maturation and movement of maturing fish toward inland streams of origin? Larry LaVoy recognized problems with this assumption in his response to the Panel's questions after workshop 1.
- Larry LaVoy should please clarify what he means by a “more conservative prey abundance estimate”. Does he mean that his calculations generate a larger or smaller prediction of additional prey available to KW than would actually be expected under a competing risks of death model?
- Larry LaVoy should please clarify what is meant by “preterminal ocean fisheries”. We assume he means marine fisheries in Puget Sound and/or near mouths of spawning streams but in marine waters.

HIGH (FRAM) for all four items above

Recommended Analyses

- Consider adoption of a continuous competing risks of death mortality model to better approximate the plausible impact of killer whale predation on Chinook and to better predict the potential increased consumption of Chinook by killer whales if fishing were removed as a cause of death in certain times/areas. Section 4.2 provides some further discussion on how predation by SRKW might be treated.

HIGH

- Explore whether age-specific maturation probabilities may be used in FRAM to generate guesses of “inland” Chinook that might be available for pre-terminal marine fisheries and KW ;

HIGH (FRAM)

- Fit size selectivity functions to data that more likely reflect the actual abundance of mature individuals from inland populations that might be available for KW

HIGH (FRAM)

Longer Term Recommendations

- Additional sampling for SRKW prev items at the same time that test fishing is carried out would provide additional useful information concerning size and species selection by KW
- More intensive and extensive winter feeding studies seem essential to resolve uncertainty in degree to which SRKW rely on Chinook during winter months.

9.0 RATIO OF CHINOOK FOOD ENERGY AVAILABLE COMPARED TO CHINOOK FOOD ENERGY NEEDED BY SOUTHERN RESIDENTS WITH (AND WITHOUT) FISHING

9.1 Key Questions and Preliminary Responses

Review the analysis conducted to date

1) Are the methods employed to estimate the prey ratios under alternative fishing scenarios scientifically reasonable?

- The methods are not entirely clear. From the standpoint of KW demand, the bioenergetics approach is valid, though several of the assumptions are not adequately tested. It is desirable to compare the consumption estimates from the Noren model to estimates from captive KWs. Are they in the same ballpark? It is also not clear that the energetic demand is properly allocated to various prey categories. When allocating predator demand for energy to prey, it is important to apportion demand to prey categories based on the diet composition that accounts for differences in body size and caloric density of different prey items. It was not clear from the workshop if the frequency of occurrence data used to characterize KW diets had been transformed to reflect the difference in body mass and caloric density of prey. Clarification and/or updated calculations are needed here.
- For the bioenergetics model, it was assumed that KWs were at metabolic equilibrium with respect to seasonal consumption and growth. However, if the summer is a critical time for accumulating energy stores, then the estimates for summer predation rates could be seriously low. If the summer is a time when KWs lose weight or energy, then the bioenergetics estimates for summer consumption rates will be too high. Additional data on seasonal patterns of body condition would improve the existing calculations. If no such data exist, then a sensitivity analysis should be performed that considers scenarios of seasonal fattening and energy loss.
- As described elsewhere in this report, the 'prey supply' component of the ratio estimates are based entirely on FRAM output, yet very little information is given about how FRAM works. As such, it is essentially impossible to assess the validity of the supply component of the predator-prey ratios.

2) Do you have specific suggestions to address key assumptions and uncertainties?

- See answer to #1

3) How sensitive is the ratio analysis to its component parts? (e.g., selectivity function, whale population size and structure, percent of Chinook in diet, food energy value of prey, etc.)

- This is really a question the KW team should be answering. Our feeling is the ratio analysis is probably sensitive to many of the assumptions involved in their calculation. The sensitivity analyses presented at the workshop considered only a very conservative range of the potential model uncertainties.

4) In your expert opinion, do forage ratios provide meaningful information about potential prey limitation in the SRKW?

- We do not believe the forage ratios provide much insight into prey limitation in SRKW. The main deficiency is that there is no objective means with which to evaluate the ratios. To do this requires a functional response that describes whale fitness or vital rates as a function of the supply:demand ratios. Without such a functional response there is no way to interpret the ratio (unless of course it is < 1 at which point there is clearly a prey deficiency).
- Additionally, the comparison between the SRKW and other apex predators in other ecosystems is not well justified and, again, difficult/impossible to interpret. There are several reasons for this, the most important of which is that the predator demand component of the ratio should really include the demands on Chinook salmon (or any prey) by the entire community of predators that rely on it. It is possible that KW consume a larger component of the PS Chinook stocks because there are fewer other important apex predators compared to other ecosystems.
- As mentioned elsewhere, more effort should be focused on assessing possible empirical linkages between variation in Chinook abundance and vital rates of KWs.

5) How can we improve comparisons to ratios for other marine predators and systems?

- We do not believe this exercise provides any meaningful information about either the ecosystem or the biology of SRKW. We suggest dropping these analyses. Such analyses might provide some insights into the ecology of the Salish Sea ecosystem if directly comparable models were generated for the Salish Sea and other ecosystems (i.e. same assumptions, taxonomic resolution etc.) The ratios presented at the workshop 1 in September 2011 were derived from many disparate models with very different assumptions.

6) What more can we learn from the ratios? For example, is it possible to estimate what the ratio should be in a given time and area to support survival and recovery of the whales?

- We see little value in calculation of the supply:demand ratios. These do not provide any direct and defensible links between Chinook populations and KW demographic processes – links that are critical to assessing the potential effects of fisheries on KW viability.

9.2 Information and Analyses Recommended by Workshop 2

Information Requests

- Please clarify how diet composition (% occurrence) was then translated into predator demand on various prey types that accounts for body size and energy density differences among prey.

MEDIUM

Recommended Analyses

- An analysis that assessed the sensitivity of the KW demand calculations to the assumption that KW's are at metabolic equilibrium (i.e., they grow continuously throughout the year) would shed light on the utility of investing in more research to quantify the seasonal growth dynamics. For example, if the summer season is a period of substantial annual growth, how much do the SRKW predation rates on Salish Sea Chinook increase to meet this demand? Similarly, if SRKW lose substantial weight during the summer, how much does this seasonal growth dynamic affect the estimate of predation demand on Chinook? Is it known whether summer is a time of fat accumulation or burning of energy reserves? Would new photogrammetry techniques help answer this question?

MEDIUM

- As mentioned elsewhere, a comparison between the SRKW bioenergetics model and feeding rates of KW in captivity would be useful for verifying that the model is operating within the right ballpark

LOW – but likely easily implemented

Longer Term Recommendations

- More emphasis should be placed on linking the demographics of SRKW to variation in Chinook abundances to properly clarify the problem at hand. The trophic ecology component of the research program is only useful in identifying specific mechanisms that could cause the observed dynamics.

10.0 CHANGE IN KILLER WHALE POPULATION GROWTH RATES ANNUALLY, ABUNDANCE OVER TIME AND SPECIES SURVIVAL AND RECOVERY

10.1 Key Questions and Preliminary Responses

Review the analysis conducted to date

General comments

It is not clear why (in the “NMFS Biological Opinion Analysis” statement in the reading list description of this topic) fecundity is the only growth rate component that should be influenced by Chinook abundance. Analyses by Wade (2007) showed strong relationships between SRKW survival (of calves and old males, especially) and CTC Chinook indices.

Workshop presentations (e.g., Agness) and the text above refer to a "small but measurable reduction in population growth because of fisheries...". This seems contradictory given that uncertainty in FRAM abundance estimates is completely ignored. If the effect is small, then it is probably **not measurable** once FRAM uncertainty is taken into account.

1) Based on your expert opinion, what level of confidence would you assign to the conclusion that predicted changes in Chinook salmon abundance caused by fisheries affect the population growth rate of the SRKW?

We cannot assign a specific confidence measure at this time because we do not have a clear understanding of the relative impact on Chinook abundance of natural mortality, fisheries, and killer whales (both SRKWs and NRKWs).

- i. Analyses of Chinook salmon natural mortality rates have not been provided to convince us that the constant natural mortality rate assumptions used in CTC and FRAM models are realistic. Higher abundances of both killer whale populations implies higher natural mortality provided that mortality components are additive.
- ii. There is a lack of consistency among analyses of fecundity and survival relationships to various Chinook salmon abundance indices. In particular, it is not clear why some Chinook abundances are correlated to survival in some analyses and not others.
- iii. We have not actually seen direct posterior distributions of the population growth rates, possibly broken out by SRKW pods.

2) Based on your expert opinion, what level of confidence would you assign to the conclusion that predicted changes in Chinook salmon abundance caused by fisheries increases the risk of extinction of the SRKW population?

For reasons similar to those given for Question 1, we cannot assign a confidence level given our current understanding of the data and analyses. Based on the analyses presented at the workshop, the main factors influencing extinction risk are the frequency and magnitude of catastrophic events (Krahn et al. 2004), which are both independent of salmon abundance.

10.2 Information and Analyses Recommended by Workshop 2

Information Requests

- See above requests for clarification of FRAM abundance calculation methods
HIGH (FRAM)

Recommended Analyses

- See earlier recommendations to provide Bayesian posterior distributions of SRKW population growth rates (i.e. Section 5)
HIGH

Longer Term Recommendations

- To the extent possible, assess changes in natural mortality rates of Chinook salmon. This could possibly be done using CWT releases/returns to hatcheries, age-composition, and other methods. Using estimates of natural mortality that are constants and based on old data is a large assumption, but improving our understanding of mortality is a long-term project.

11.0 REFERENCES

NOTE: This list only contains the references cited that were not already included in the reading list.

Bonenfant, C., J. M. Gaillard, T. Coulson, M. Festa-Bianchet, A. Loison, M. Garel, L. E. Loe, P. Blanchard, N. Pettorelli, N. Owen-Smith, J. Du Toit, and P. Duncan, 2009. Empirical evidence of density-dependence in populations of large herbivores, volume 41 of *Advances in ecological research*, pages 313–357.

Caswell, H., 1996. Analysis of life table response experiments .2. Alternative parameterizations for size- and stage-structured models. *ECOLOGICAL MODELLING* 88:73–82. Clark, J. M., 2007. *Models for ecological data*. Princeton University Press., Princeton, NJ.

Clark, J. S. and C. N. Bjornstad, 2004. Population time series: Process variability, observation errors, missing values, lags, and hidden states. *Ecology* 85:3140–3150.

Trites AW, Joy R. 2005. Dietary analysis from fecal samples: how many scats are enough? *Journal of Mammalogy* 86: 704-712.